WIND TECHNOLOGIES
EVOLUTION, STATUS & DEVELOPMENTS

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1.0 Background

Increasing population, aspirations for improved living standards and general economic and industrial growth in India sustains an increasing energy demand. However, due to the environmental constraints and the risks associated with high dependence on fossil fuel based energy generation, further capacity additions with conventional centralized methods of power generation would be questionable. As a result of increased attention towards alternative forms of energy and methods of conversion, significance of renewable energy devices operating in dispersed and decentralized mode, as serious components of modern energy supply has been growing. Wind energy is one of the clean and renewable energy sources which holds the promise of meeting a significant portion of energy demand in both, direct grid connected mode, stand alone as well as remote 'niche' applications (eg. water pumping, desalination, telecommunications etc.) in developing countries like India.

Large scale utilization of wind energy for power generation in California, Europe and India and demonstration projects in several other developing countries (table 1) have beyond doubt established the viability of this technology in potentially windy regions. In developing countries renewable energy technologies and amongst them wind technology have a very important role to play in meeting the increasing energy needs while ensuring sustainable development. There has been a general increase in the awareness towards wind energy technologies all over the world. A great deal of interest is being shown by media, academicians, students, international funding and aid organizations, environmentalists, industries and policy makers. More people are seeking information on wind powered systems than ever before. In the next few sections of this document, a general review of the different types of wind energy systems is given.

Country	Capacity (MW) 1992	Planned	(year)
Europe			
Denmark	[illegible]	[illegible]	(1993)
Netherlands	[illegible]	[illegible]	(1993)
Germany	[illegible]	[illegible]	(1993)
U.K.	[illegible]	[illegible]	(1993)
Greece	6	26	(1995)
Italy	6	30	
Sweden	[illegible]	8	(1993)
Belgium	6	[illegible]	
Spain	45	[illegible]	(1993)
[illegible]	[illegible]	[illegible]	(1993)
[illegible]	[illegible]	[illegible]	(1993)
USA			
California	[illegible]	[illegible]	
[illegible]	[illegible]		
Oregon	1	1	
Minnesota	1	6	
[illegible]	[illegible]	1697	[illegible]
Asia			
India	42	500	(2000)
China	[illegible]	25	(1993)
[illegible]	67	525	(2000)
Others			
[illegible]	1	[illegible]	
[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	

Table 1: Windfarms Worldwide.

3.0 Developments and Prospects in India

India has been quick to realize the potential and significance of wind power. Till recently, the country was regarded as a region with low or mediocre wind speeds However, wind mapping and wind monitoring program initiated by the Ministry of Non-conventional Energy Sources (MNES) has identified several sites (table 2) with adequate winds and has enabled a realistic assessment of the wind regime in the country.

3.1 Wind Climatology

Large scale flow of wind over the Indian peninsula is mostly dominated by the monsoon circulation system. In winter the country experiences weak pressure gradient as large scale flow from the north and north east is blocked by the Himalayas. A weak cyclonic circulation is experienced in early spring Uniformly strong winds are experienced through out during the period March to August. South-west monsoon starts in May-June with a predominantly south-westerly flow from the Indian ocean The north-east monsoon begins from October but is not as strong as the south-west monsoon except for in certain regions of the country

Annual wind speeds of over 20 kmph are experienced in the coastal Gujarat, Tamil Nadu, Karnataka, Andhra Pradesh and parts of Kerala and Orissa Other than the coastal areas, enhanced wind speeds (annual average of 25-30 kmph) are also observed at some inland locations due to complex terrain effects Sites that experience wind speeds higher than 18 kmph are listed in the table 2.

3.2 Developments

MNES undertook installation of a number of windpumps, stand alone systems and windfarms in the potential regions As of today, over 3000 wind pumps and 110 stand alone systems of 50 watts to 4 kW unit capacities have been installed in the different regions of the country The first grid connected windfarms in India were installed in 1986 in the coastal areas of Tamil Nadu, Gujarat, Maharashtra and Orissa The performance of these windfarms was encouraging and the capacities at these sites was doubled While the grid connected wind turbines have performed well, the experience with wind pumps and stand alone systems has not been encouraging largely because the maintenance and monitoring of small units dispersed in remote regions of the country could not be effectively carried out. However, their remains a large potential for application of such technologies in India

By March 1993 about 54 MW of windfarm capacity (fig. 2) had been installed in the country This capacity comprises of 37.3 MW of demonstration windfarm projects including 20 MW windfarms set up under Danish aid program, 0.575 MW projects with individual wind turbines and 16.025 MW of windfarms under private sector In addition a further 16.64 MW of demonstration windfarm projects are presently under implementation Under favorable policies and incentives private sector organizations are planning or implementing several large projects in potential states of which about 32 MW is planned in Tamil Nadu and the total windfram capacity in this state is expected to be 75 MW by March 1994, in Karnataka 24 MW capacity has been allocated by the government to the private sector, in Andhra Pradesh government has allocated land to the private sector for development of

130 MW windfarms and in Gujarat private sector has shown interest in setting up 200-300 MW windfarms, about 25 MW of private sector windfarms are likely to be commissioned in coastal Gujarat by March 1994. An 85 MW private sector windfarm project is planned for implementation with GEF/IDA/DANIDA assistance. The assistance is being channelized through Indian Renewable Energy Development Agency (IREDA) The 8th five year plan targets a total of 500 MW windfarm projects in the country The incentives for setting up windfarms are summarized as follows:

- The private sector is allowed to set up power projects.

- All wind electric systems are exempt from central excise

- Under the Income Tax Act, the government of India is allowing 100% depreciation in the first year of commissioning of a windfarm.

- Soft loans for setting up windfarms, currently @ 14% are being offered by IREDA

- There is a concessional duty of 25% imposed on import of wind turbines However, some components listed below are allowed to be imported free of duty.

Blades
Gear box
Brake assembly
Yaw components
Brake hydraulics

Sensors
Special bearings
Hubs
Flexible coupling
Controller parts

- The potential states are offering some additional incentives for windfarm developments These incentives are summarized in table 3

Technical viability of windfarms is well established and it is estimated that in the potential states, 25% of the peak generating capacity can be based on wind. The cost of electricity generation from windfarms computed with standard marginal rate of return of 12% has been found to vary from Rs 2 0/kWh to Rs 4 5/kWh Wind turbines are now being manufactured in India with major indigenous components and some imported components. The potential states for wind farm development are marked in figure 1. The windfarms installed till March 1993 are shown in figure 2

Table 2: Sites experiencing annual wind speeds over 18 kmph.

Sl No.	Station	Mean annual wind speed (kmph)	Sl No.	Station	Mean annual wind speed (kmph)
	Tamil Nadu			Karnataka	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	Kayathar	20 3	4	Jogimatti	30 9
5	Muppandal	25 5	5	Bommanahalli	18 7
6	Sembagaramanpudur	21 7	6	Hanumanhatti	20 4
7	Puliyankulam	18 9	7	BB Hills	27 1
8	Alagiyapandiyapuram	21 4		Andhra Pradesh	
9	Talayathu	20 8	1	Tirumala	20 4
10	Ayikudy	21 4	2	Payalakuntla	20 5
11	Kattadimalai	23 9	3	Narasimhakonda	20 2
12	Rameswaram	24 3	4	Kakulakonda	24 0
13	Kethanur	22 7	5	MPR Dam	20 0
14	Metukadai	18 4	6	Ramagiri-I	19 7
15	Pongalur	20 6	7	Bhimunipatnam	19 1
16	Arasampalayam	21 4	8	Ramagiri-III	18 3
17	Edayarpalayam	23 4		Kerala	
18	Ottapidaram	18 2	1	Kanjikode	22 3
	Gujarat		2	Kottathara	19 5
1	Harshad	20 0	3	Kottamala	18 4
2	Okha	19 4	4	Ponmudi	19 7
3	Mundra	19 4	5	Ramakalmedu	30 4
4	Surajbari	19 9		Maharashtra	
5	Okha Madhi	19 0	1	Vijaydurg	19 6
6	Navi Bander	19 9	2	Panchgani	18 2
7	Dhank-I	24 2	3	Chalkewadi	19 9
8	Dhank-II	24 9		Lakswadeep	
9	Kukma	19 2	1	Agatti	18 0
10	Kalyanpur	21 9			
11	Bamanbore-II	20.5			

Source Annual report 1992-93 MNES

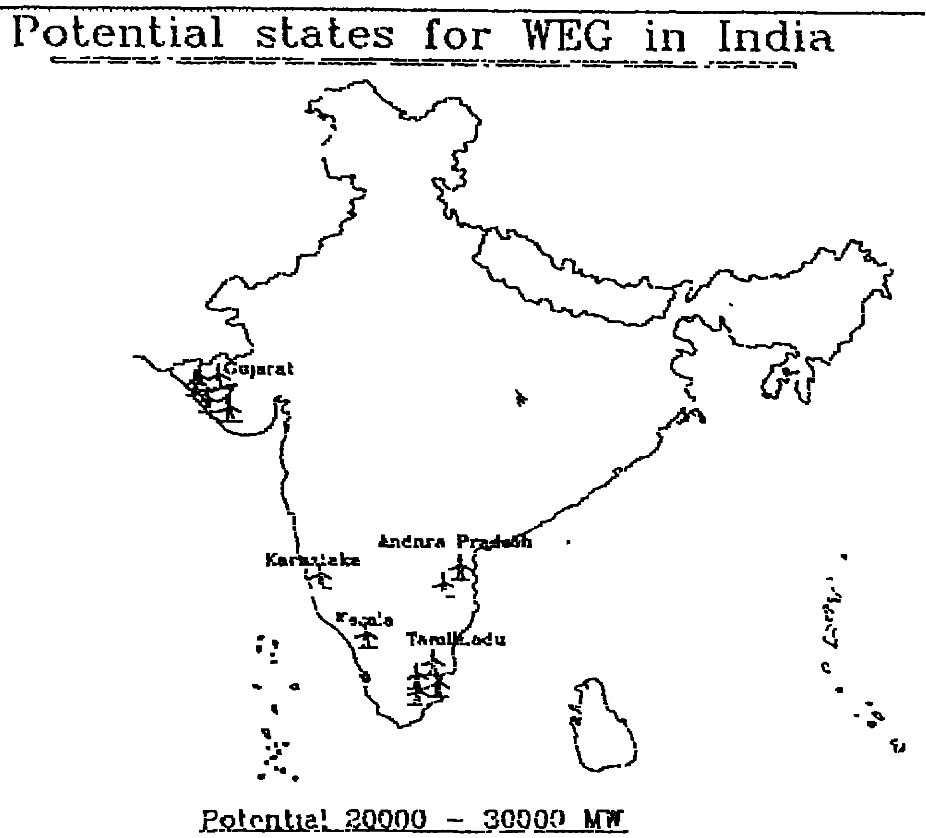

Figure 1 Potential states for the Installation of Windfarms in India

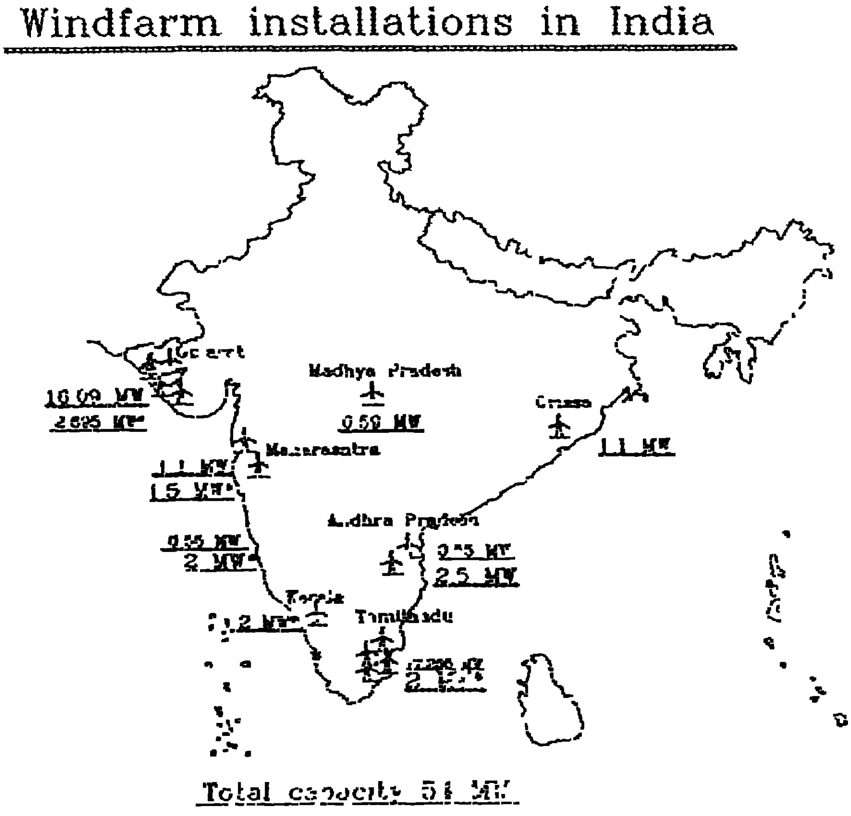

Figure 2 Windfarm Installations in India

Table 3: Summary of Incentives in Different States

Sl No.	Area	Andhra Pradesh	Tamil Nadu	Karnataka	Gujarat
1	Power Wheeling & Banking	Introduced	Introduced	Introduced	Introduced
2	Buy back of generated surplus power by SEB	Permitted	Permitted	Permitted	Permitted
3	Selling and sharing of generated power to other industries	Yet to be	Yet to be	Permitted (Subject to a fee)	Permitted (any industrial unit can be declared beneficiary of a given windfarm)
4	Charges for Power Wheeling	2% of energy generated	2% of energy generated	2% of energy generated	2% of energy generated
5	Charges for Power Banking	Included in above	- do -	Included in above	Included in above
6	Buy back by SEB	Negotiable	@ Rs 1.00/kWh	@ Rs 1.25/kWh	@ Rs 1.75/kWh
7	Capital subsidy	Up to Rs 15 lac per project	10% of the project cost	As extended to other industries	-

4.0 State of the Art of Technology

Wind powered systems are normally classified by applications into Grid Connected Wind Electric Generators (GCWEG), Autonomous and hybrid systems and Direct Shaft Powered Systems i.e. wind pumps (mainly for water pumping). However, while reviewing the 'state of the art of technology', it is appropriate to classify the systems by their levels of development, therefore, the description should cover a range of systems from the windmills of the earliest times to the concepts for future wind powered machines.

4.1 Obsolete Wind Turbines

The earliest recorded traditional windmills in Europe and some parts of Asia are not made now. The traditional European windmill is found mainly along the Atlantic coast, the North Sea, Baltic sea and to some extent in the Mediterranean region These windmills can be classified into two main types i e, rotating roofed and rotating caged windmills The early American windmills are similar to North European windmills.

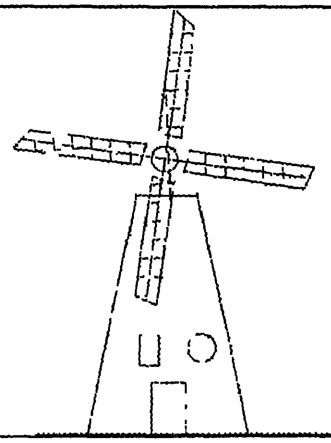
Figure 3 Rotating Roofed Windmill

Rotating-roofed windmills: The rotor is installed on a conical roof which can turn above the building, made of stone The roof is connected downwards by a beam which allows the sails of the mill to be oriented into the wind Such windmills had four bladed rotors of sail.

Figure 4 Portuguese Windmill

Rotating-caged windmills The shaft of the wheel is linked to the cage which contains the mill stones and the whole mill is placed on a spindle

Portuguese windmills In some Portuguese mills, the sails were made of triangular jib-shaped canvas, stretched between 8 or 10 poles.

Ancient Persian and Chinese windmills: The ancient Persian windmills were vertical axis windmills with a stationary screen while the ancient Chinese windmill had sails which operated like swinging blades.

4.2 Commercial/Proven

Two and three bladed horizontal axis wind turbines are being installed on a large scale in grid connected and autonomous modes while multi-bladed rotors are

used for direct pumping of water with reciprocating pumps. Reciprocating pumps require greater initial torque which is developed to a greater extent in multi bladed turbines (12 to 8 blades). The vertical axis Darrieus turbines have been tried to some extent for electricity generation but due to a high starting torque required these systems could be disseminated only on a limited scale. The one blade HAWT is the result of an effort to cut down material weight and cost. The problem of balancing is taken care of by a counter weight. The system though commercially available has not been extensively used till now.

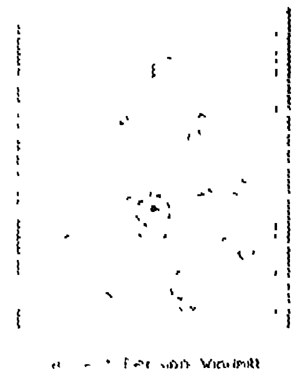

Figure 5 Ancient Persian Windmill

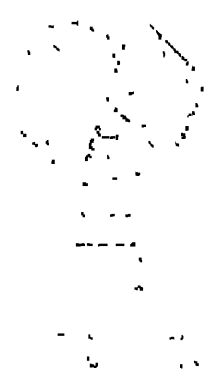

Figure 6 Cretan Wind Turbine

4.3 *Demonstration/Developmental Level*

Here we describe the systems which are either being demonstrated or await further technological breakthroughs before being extensively used

Variable and fixed geometry Darrieus rotors
Developed at the University of Reading in U K.. This model is result of an effort to limit the speed of rotation of a Darrieus rotor.

Savonious rotor This is a vertical axis turbine with two half cylinders as blades. Though not as efficient as the horizontal axis wind turbines with the aerofoil blades these systems have been found to be useful due to the ease with which the rotor can be fabricated This rotor named after its inventor Sigurd Savonious was patented in 1929 Being very simple in construction, it has the potential for large scale use in decentralized mode particularly in developing countries Experimentation is being carried out with improved versions of Savonious rotor

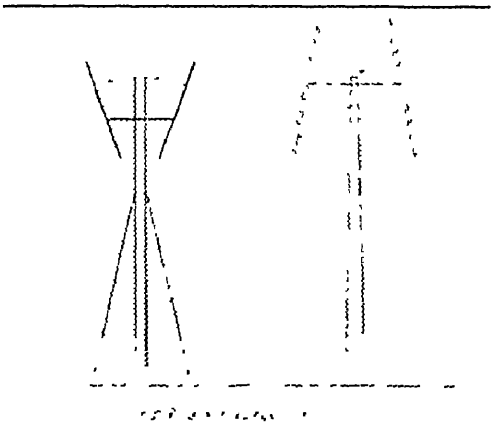

Figure 7 Darrieus Rotors With Variable Geometry

Wind-diesel hybrid systems· These systems are meant for decentralized applications where the diesel consumption can be significantly reduced. Many systems have been installed on an experimental basis to work out the optimum configurations and control strategies These systems are discussed in detail in section 6 0.

Savonious-Darrieus Systems: The Darrieus rotors require an external starting torque in order to reach the operating conditions. It is possible to start the Darrieus rotor with the aid of a Savonius rotor.

Flapping-Blade Machines: This is a machine with flapping blades. This kind of system results in a greater noise and wear.

Nguyen Vinh rotor turbine: The rotor consists of three blades made up of a half cylinder combined with a flat plate. The performance of this rotor is comparable to that of the Savonious rotor.

Arnbak windmill: This windmill consists of two identical cylindrical parts. Each part has an elliptical section and is offset by 90° with respect to the other in order to make the torque more uniform and to facilitate starting.

Gyromill: This windmill is somewhat similar to Darrieus rotor with the option of variation in blade inclination achieved by guide rods or cams. Trials have shown that the cyclogyro has better efficiency than the classical Darrieus rotor at low speeds.

De Lagarde design: This is a Darrieus rotor with moving blades. The centrifugal forces on the centers of gravity of the eccentric (relative to axis of rotation) blades makes them turn through a certain angle resulting in the machine being self-regulating.

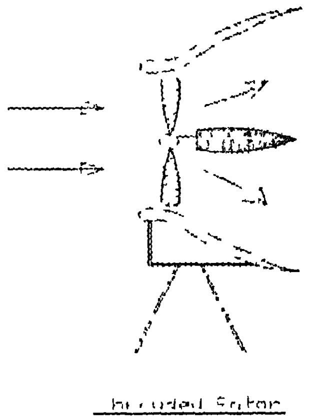

Figure 10 Shrouded Wind Rotor

Evans machine: This is similar to De lagarde design but the regulation is done by means of a runner and a spring which applies force to the leading edge.

Rolling band machines: An array of blades is mounted on a system of bands passing over two pulleys. The array is placed perpendicular to the wind which flows through it twice. A blade reversing mechanism allows a driving force to be developed on both the upwind and downwind blades.

Oscillatory machines: This consists of an aerofoil section mounted on a system of articulated rods attached to pulley wheels. The mechanical linkage is such that the angle of incidence changes continuously.

V-VAWT: This machine was originally conceived by Derek Taylor at the Open University, U K.

5.0 Grid Connected WEG

The grid connected wind electric generators (GCWEG) have been installed on the largest scale and most of these systems are HAWTS. The systems described in this section are also HAWTS. The thrust in the recent years has been towards a greater efficiency, components reliability and a reliability in energy supply to the end use. As a consequence, the governing mechanism, controls, braking system, protection, load management and grid interphase in these machines tends to be more sophisticated. The GCWEG are produced in a wide range of ratings and sizes varying from 50 kW to 6000 kW, however, the largest number of machines installed so far lies in the 100 kW-300 kW range. It is felt that in very near future most of commercially available GCWEG will be in the range of 500 kW-1 MW. The electricity generated by the system varies with wind speeds in accordance with the power curve specified by the suppliers[1]

In an ideal WEG the power output in the cut-in to rated wind speed range is a cubic function of wind speeds. However, in practice the power output response is a linear or a near quadratic function of wind speeds.

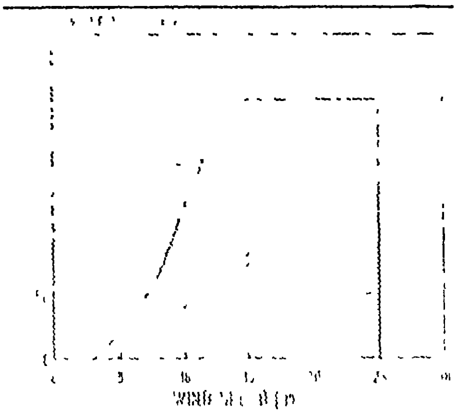

Figure 11 A typical power curve

5.1 Subsystems of GCWEG

The major subsystems and components of GCWEG shown in table 4 are briefly described as follows

Structure: The main components of the structure are the *tower*, the *nacelle* and the *foundations*. The tower height is normally recommended by the suppliers who allow a certain minimum clearance between the lowest tip of the blade and ground level. Towers are either tubular or lattice type. Both the tubular and lattice towers are usually made of galvanized steel. However, concrete towers of tubular type are also in use. The nacelle is basically the engine bed of the turbine supporting and containing all the machinery i.e *rotor shaft, gear box, hydraulic brake mechanism, generators, yaw mechanism, some controls* and other accessories. The nacelle is mounted on the top of the tower such that it can be rotated about the tower axis by the yawing mechanism. One of the large gear wheels of the yawing mechanism is fixed to the tower top while the other engaging member is fixed to the nacelle while the nacelle rests on the tower top on pads which are free to move and hence allow for the yawing movement of the nacelle. The nacelle and its contents are covered by an FRP or metallic cover.

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[1] The power curve is characterized by three characteristic wind speeds defined as follows. Cut-in wind speed is that at which the generator is connected to the grid and it starts generating electricity. Cut-out wind speed is that at which the generator is disconnected and the shaft is braked due to excessively high wind forces on the rotor and the structure and the Rated wind speed is that at which the rated power of the WEG is delivered.

Table 4: Components and Sub-Systems of a GCWEG

Typical GCWEG	Structure	Platform		
		Security Wire Assembly		
		Tower Sections		
		Steps		
		Foundation		
	Nacelle	Transmission	Speed Increase Gear Box	
			Shaft Assembly	Shafts
				Front/Rear Bearings
				Hub Connection
				Disk Brake
				Couplings
			V Belt Drive for twin generator system	
		Generation System	Large Generator	
			Small Generator (in twin generator system)	
		Brake Mechanism	Brake Oil Tank	
			Pump	
			Motor	
			Valves	
		Yaw Mechanism	Yaw Gear	
			Pinion	
			Yaw Motor	
		Engine Bed		
		Nacelle Cover	Cover Fix Attachment	
			Cover	
	Rotor	Blades		
		Nose Cone		
		Hub		
	Control Unit	Microprocessor		
		Conductors & Relays		
		Sensors	RPM Sensors	
			Temperature Sensors	
			Vibration Sensor	
			Anemometer	
			Wind Vane	
			CT	

Prime Mover: The prime mover of a wind turbine is usually known as a *rotor*. The rotor in the case of GCWEG has a horizontal axis and consists of 2 to 3 *blades* These blades which have an aerofoil section are fixed to the *hub*[2]. Most of the wind electric generators have a *nosecone*[3] made of the same material as the blades and fixed at the center of the rotor. The blades and nosecone can be made from metal alloys (steel, aluminum) or FRP. Most of the blades manufactured today are FRP blades while earlier aluminum blades were also used Wood-epoxy has also been tried in some cases with reasonable success There are also some commercial WEG using wood-epoxy for the rotor blades In some machines *blade-tip* is made as a separate unit whose orientation with respect to the balance of the blade profile can be changed Tip which can be activated by aerodynamic/centrifugal forces acts as a brake in the event of high rotational speed of the rotor In the case of a failure of hydraulic braking mechanism the tip-brakes act as double security check there by preventing failure of the blades. The root of the blade is made either of painted, plated or galvanized steel. In some machines the complete blade or tip is activated to go out of wind prior to braking in order to ensure soft braking

Transmission The transmission system of a GCWEG is housed in the *nacelle*. The gearbox normally consists of two stage gear train stepping up the RPM from 30-40 to 1100-1200 In the case of small wind generators, the transmission system consists of the rotor shaft directly coupled to the generator, which is housed in the nacelle usually made of FRP The turbine is protected from

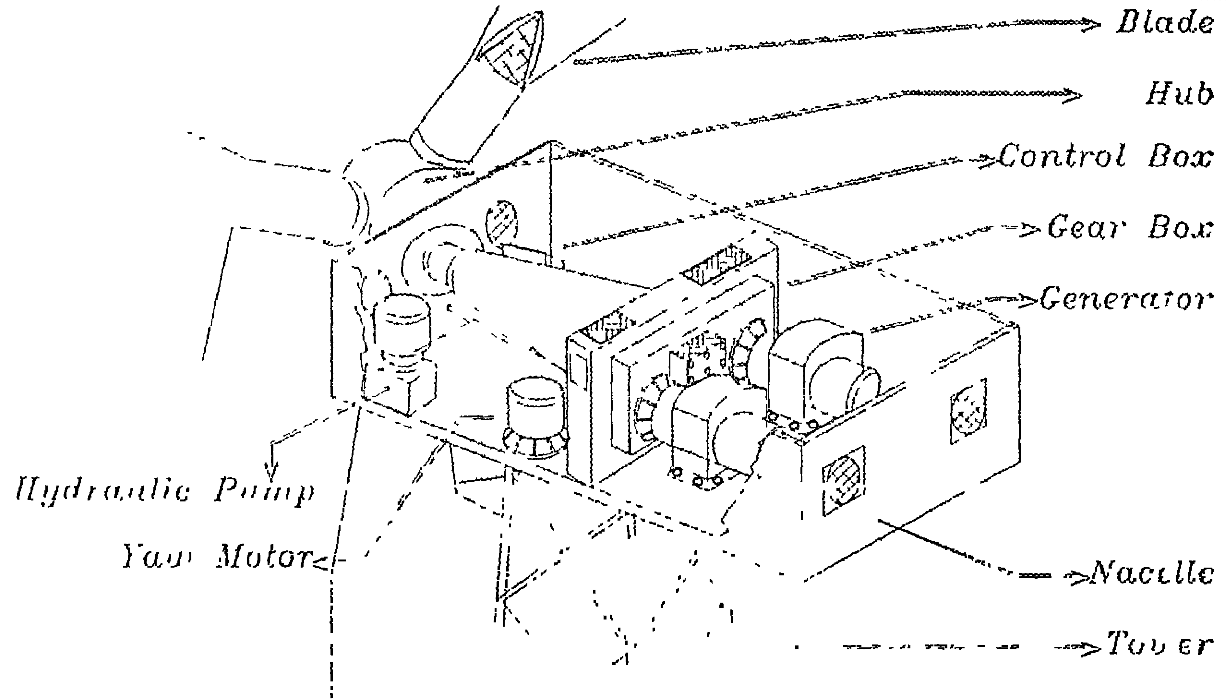

Figure 12 A typical Wind Electric Generator

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[2] *Hub* is an attachment through which blades are attached to the transmission

[3] *Nosecone* covers the hub of the rotor and uniformly diverts wind flow on to the blades or around it, thus minimizing the losses

high wind speeds by autofurling of the tail. The transmission system of wind pumps is discussed in section 7.0

Generating Unit As mentioned above the generating unit is also mounted in the nacelle. Most of the Grid Connected Wind Electric Generators (GCWEG) have *induction generator* as the power generating unit. The use of *synchronous generators* is limited. This is due to various advantages associated with cost, construction and operation of induction generators. The induction generator consists of a fixed core, *the stator*, carrying a three phase winding in slots on its bore. A *rotor*, carrying a *cage or slip-ring winding*, also in slots, is free to rotate within the stator. The stator winding is connected to three phase source (the grid) and a uniform rotating magnetic field is produced in the gap. This induces an electro motive force (e.m.f.) in the rotor winding, and the currents produced interact with the rotating field to develop a torque. The same induction generator can also operate as a motor. If the rotor is at rest, the frequency of the induced e.m.f. and currents in the rotor are the same as that of the rotating field. The rotor currents, therefore, produce a magnetic field which rotates with the stator magnetic field and is directed in opposition to it. If the rotor is free to rotate, the torque will cause it to move round in the direction of the stator field i.e. the *motor mode*. In *generator mode* the rotor is driven at hypersynchronous speed so that the slip is now negative, the rotor, e.m.f. is negative and the total stator current has an active component in opposition to the total stator e.m.f. thereby indicating conditions of electricity being fed into the grid. The construction and operation of synchronous generator is much different. A d.c. source is used to supply current to the rotor by means of carbon brushes and slip rings. The rotor is rotated by the prime mover and an A.C. current can be tapped from the stator. Synchronous generators are normally used in large thermal or hydel power plants. While feeding electricity to the grid, synchronization is a major problem. In case of hydel or thermal projects this is achieved by varying the r.p.m. of the prime mover till synchronous speed. Varying of r.p.m. in the case of wind turbines, however, presents a difficult practical problem. In case of WEG with synchronous generators the A.C. output from generator is rectified and inverter is used to produce 50 Hz or 60 Hz output. In some GCWEG there are two generators, in order to achieve efficient power conversion from lower rating generators at low wind speeds. Figure 12 shows a typical wind turbine with two generators of equal capacity

Control Unit The major functions of the control unit are protection and regulation of the system. A control unit can be a relay based system or a microprocessor based system. The typical functions of the control unit are described as follows.

- Protection against over speed of the propeller: An inductive sensor near the hub senses the r.p.m. of the rotor. In case the rotor r.p.m. exceeds the specified limits, the turbine is braked and an indicator identifies the fault

- Protection against high wind speed. At wind speeds higher than cut-out wind speed the WEG has to be stopped. An appropriately placed anemometer senses the wind speed and at the cut-out wind speed the brake is actuated. An indicator identifies the fault. The WEG is automatically reset after the average wind speed stabilizes below the cut-out wind speed for a certain preset period of time

- Protection against high vibrations A sensor mounted on the engine bed senses the amplitude of any vibration in the structure. For amplitudes beyond the safe limits the brake is actuated and an indicator identifies this fault These vibrations can be caused by ice coating on rotor blades, turbulence or seismic activity. The turbine is reset manually after identification and rectification of the fault.

- System protection against grid supply fluctuations: The induction generator operates at hyper-synchronous speed of rotor. A change in any of the grid parameters i e voltage, frequency and asymmetry in phases beyond certain specified limits can adversely affect the generation mode/conditions for which generator is designed. These fluctuations are sensed and the generator is disconnected if the limits are exceeded Usually the machine automatically resets itself after a certain delay to avoid frequent braking

- Overload protection The current drawn by brake motor, yaw motor or drawn/generated by the generators is an indicator of overload conditions The currents are sensed by current transformers and if the value exceeds the upper limit the turbine is stopped and the fault is indicated

- Temperature faults Temperature sensors in small and large generators activate the braking system in the event of a temperature higher than the upper safe limit.

- Yawing The turning of nacelle and rotor in and out of wind is achieved by yawing mechanism which is normally very slow to avoid gyroscopic forces Every time the WEG is braked due to a fault the nacelle-rotor assembly yaws 90° out of the wind For wind speeds beyond cut-out wind speed the nacelle continues to remain 90° out of the wind In some machines during the yawing process the cable coming down from nacelle gets twisted. The control system monitors the number of twists and after a certain limit the yawing motor is activated to untwist the cable Usually untwisting is allowed only when there is no over speed, wind speed is below the rated and the yaw motor is not overloaded

- Indicators Indicators in addition to indicating the faults also indicate the mode of operation for yaw (manual/automatic), generator start (manual/automatic), clockwise and counter clockwise yaw, cable untwist, brake operation (manual/automatic), etc .

- Counters/meters A wind speed meter and a watt meter show the wind speed and the output from WEG Counters show the running time in hours of the generators

5.2 Performance Evaluation of Windfarms

It is essential to assess the performance of existing windfarms as it enables us to assess the suitability of the site as well as the technical performance of the machine in actual field conditions This also helps in future selection of technology and assessment of sites Following are some of the important parameters that are used to assess the performance of a windfarm.

Wind availability is the number of hours during which the wind speeds were within the operational range of the wind turbine within a given period - a day or month or a year.

Machine downtime is the number of hours for which the turbine did not operate due to failure or preventive maintenance within a given period Usually this is expressed in percentage.

Grid downtime is the duration for which the grid was not available for reasons like failure, preventive maintenance, accidents etc. within a given period expressed in percentage.

Capacity Utilization Factor (CUF) is defined as the ratio between actual energy generation in a year and the installed capacity multiplied to 8760 (365 x 24) hours

A typical reporting format for windfarm assessment is shown in table 5

5.3 *Performance of Windfarms in India*

The performance indicators for wind farms in Gujarat are given in table 6 It can be seen that the technical availability of wind turbines is above 80%, in the case of a recently installed windfarm at Lamba, the machine availability is about 96% Figure 13 shows that 'low wind' is a major contributor to the downtime followed by machine and grid faults

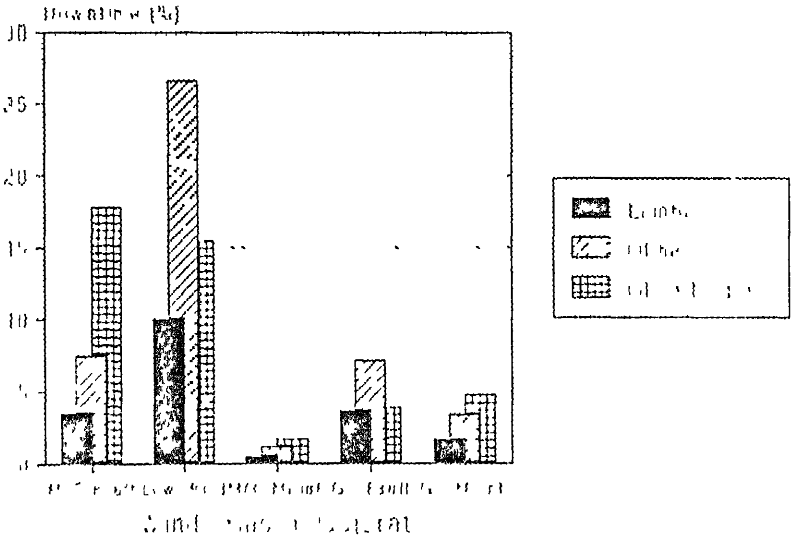

Figure 13 Downtime Analysis for Windfarms in Gujarat

The performance of pitch and stall regulated (the power curve of each is shown in figure 14) 200 kW wind turbines installed in Kayathar is compared in table 7 It can be noticed that the pitch regulated wind turbines have performed better in low wind speed months Surprisingly, however, the annual performance of the stall regulated wind turbines is better than that of pitch regulated machines Incidentally, the pitch regulated machines are also the ones which have two generators, a large generator of 200 kW and a small generator of 25 kW. At lower wind speeds the small generator will operate at a higher efficiency which could be an explanation for the better performance of pitch regulated wind turbines in lower wind speeds. The CUF values for various windfarms from 1987-1990 are shown in table 8 The layout of a typical windfarm comprising of a cluster of WEGs at a typical complex terrain site is as shown in figure 15

Table 5: Typical Reporting Format for wind farm

Site .

Year

Month	Expec. Genr.	Actual Genr.	Total Mach. hrs.	C.U.F (act.)	Wind speed lull hrs.	Mach Down time			Grid down time			Total down time
						Breakdown main. hrs.	Prev. main. hrs.	Total main. hrs.	Breakdown main. hrs.	Prev. main. hrs.	Total main. hrs.	

Table 6: Some indicators on Performance of Windfarms in Gujarat

Parameters	Lamba 10 MW	Okha 0.55 MW	O-Madhi 1.8 MW
Total M/C Hrs.	438000	87600	105120
M/C Fault Hrs	15211	6548	18703
Low Wind Hrs.	43803	23287	16277
M/C Down Time Hrs	1943	993	1799
Grid Fault Hrs	15803	6271	4116
Grid Maint Hrs	6993	2971	5009
Total Down Time Hrs	83753	40070	45904
Net Down Time (%)	19.12	45 74	43 67
Net Avail. (%)	80 88	54 26	56 33
M/C Avail (%)	96 08	91 39	80 50
M/C Fault (%)	3 47	7 47	17 79
Low Wind (%)	10 00	26 58	15 48
M/C Down Time (%)	0 44	1 13	1.71
Grid Fault (%)	3 61	7 16	3 92
Grid Maint (%)	1 60	3 39	4 77

Table 7: A comparison of pitch and stall regulated wind turbines operating at Kayathar (kWh/kW)[4]

Month	Pitch regulated	Stall regulated
April 1990	43 94	39 36
May 1990	230 09	280.22
June 1990	475 09	490 78
July 1990	473.92	477.00
August 1990	391 41	442 25
September 1990	172 85	194 98
October 1990	121 04	130.29
November 1990	35 78	33.90
December 1990	47 28	34.50
January 1991	28 58	16 83
February 1991	26 45	15.83
March 1991	20 93	15 96
Annual	2191 75	2241 53

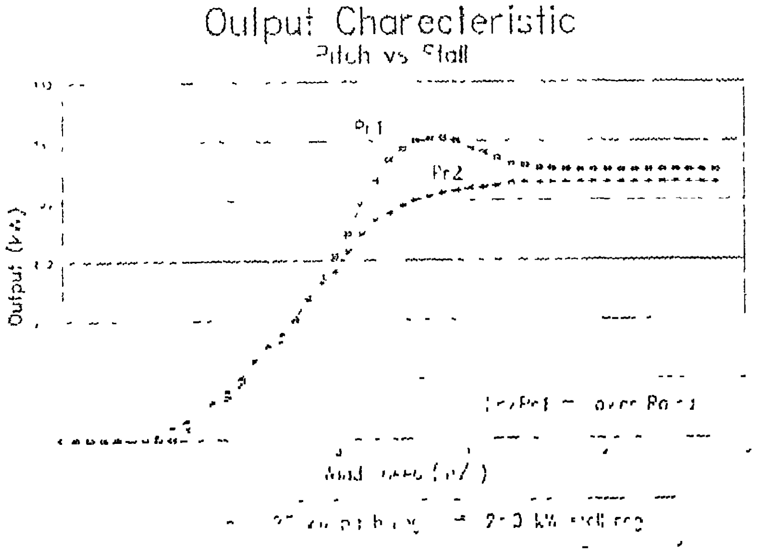

Figure 14 Comparison of Power Curves

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4 Based on 6 MW windfarm with 200 kW stall regulated wind turbines and 1 2 MW windfarm with 200 kW pitch controlled machines

Table 8: Capacity Utilization Factor[2] of Windfarms installed in India

Site	Capacity (kW)	CUF (%)				
		1987	1988	1989	1990	Avera
Mandvi I	550	17.78	15.83	13.55	14.42	15.39
Tuticorin I	550	16.60	13.53	13.66	14.41	14.55
Okha	550	17.21	11.94	9.73	13.29	13.06
Puri I	550	9.3	5.16	1.24	-	5.2
Deogarh I	550	10.86	9.7	8.28	7.3	9.03
Tuticorin II	550	16.2	14.3	15.29	16.18	9.03
Kayathar IA	1350	-	-	19.33	22.27	20.28
Kayathar IB	1200	-	-	-	23.5 (90-91)	23.5
Mandvi II	500	-	-	-	12.0	12.0
Puri II	550	-	-	-	4.15	4.15
Deogad II	550	-	-	5.65	7.28	6.46
Tirumala	550	-	-	-	9.7	9.7
Okha Madhi	1800	-	-	-	12.0	12.18
Kheda	500	-	-	-	10.08 (90-91)	10.08
Lamba	10000	-	-	-	9.18 (90-91)	9.18
Kayathar II	6000	-	-	-	24.81 (90-91)	24.81
Muppandal[1]	4000	-	-	-	29.83 (90-91)	

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[1] At this windfarm two turbines of 200 kW each were not functioning in peak generation period of July August

[2] The CUF is based on actual performance data and is inclusive of downtime associated with failure or maintenance of grid/turbines

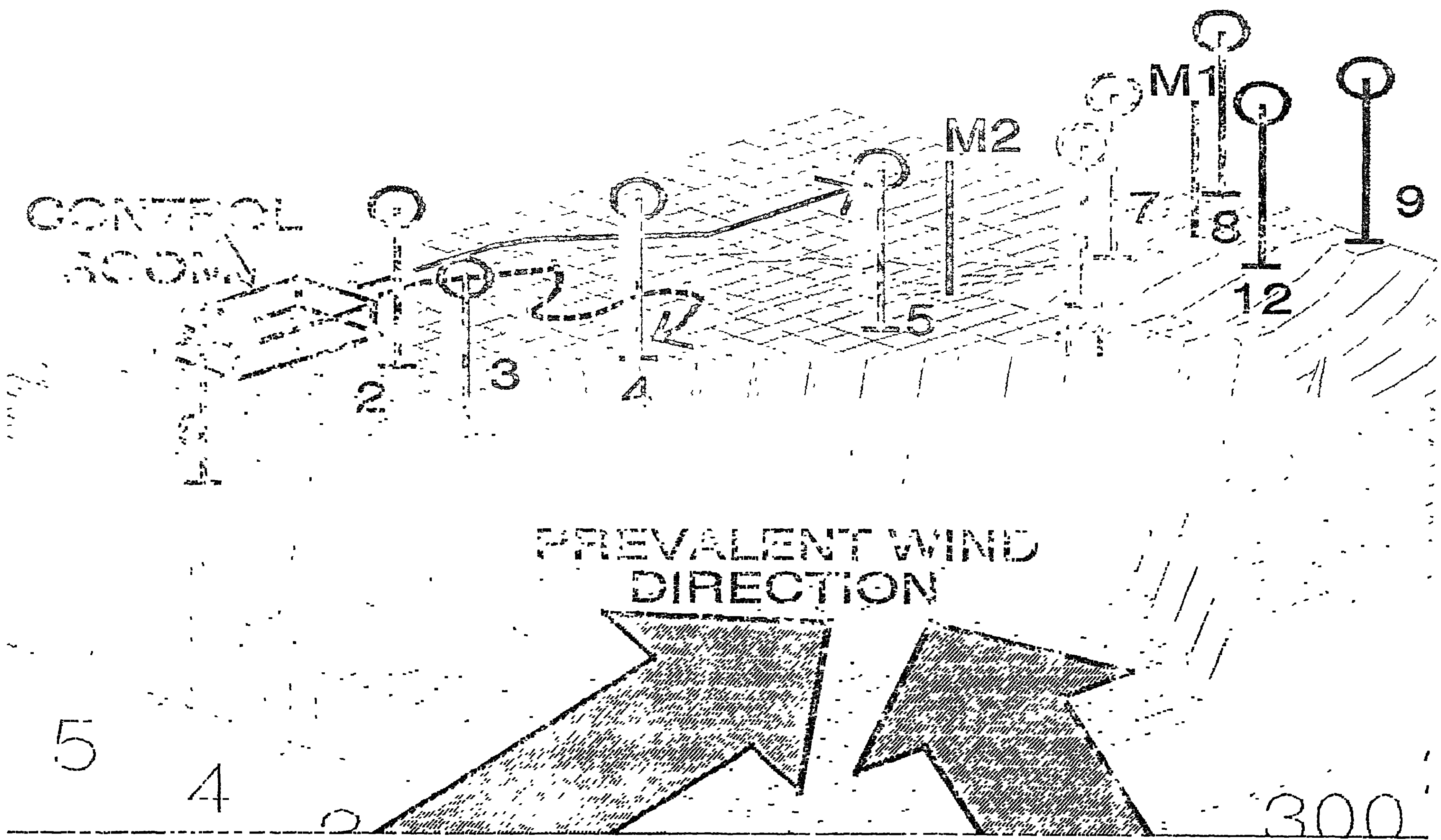

Figure 15 A Typical Cluster of Wind Turbines forming a Windfarm

6.0 Autonomous and Hybrid WEG

The Hybrid wind electric systems are operated with a fuel engine back up which can either be of a capacity higher than that of the wind plant, of the same order or smaller The components/sub-systems of the turbine in hybrid systems are similar to those of grid connected wind turbines described above. However, there are major differences in controls, wind-fuel interphase, storage and power regulation. Storage is needed to limit the start and stop cycles of the fuel engine and to ensure the reliability of supply. The autonomous systems in the strict sense are seldom used as some storage back up is always there. Depending upon the control strategy and the capacity of plants and storage the hybrid systems can be further classified into number of different types of systems Generally, the autonomous systems can be categorized in three broad groups

1) The electrical energy is only supplied by a wind turbine

2) The electrical energy can be supplied by a wind turbine and/or a fuel (diesel) generator with an installed power of the same order as the installed power of the wind turbine

3) The electrical energy can be supplied by a wind turbine and/or a fuel (diesel) generator with a much larger installed power than the wind turbine.

A brief description of these systems is given in the following sections

6.1 Autonomous System Without an Auxiliary Fuel Engine

In these systems a synchronous generator is driven by a wind turbine and there are two possible techniques to control the frequency of the autonomous grid

Blade Pitch control In this technique the angular speed (and frequency) is kept constant above certain wind speeds by blade pitch control. activated by centrifugal weights

Blade Pitch Control, combined with the Load control The pitch of rotor blades is controlled by a centrifugal controller via a hydraulic system, in such a way that the speed of the synchronous generator is kept constant, as long as the demanded power is less then the minimal power of the wind turbine When the demanded power exceeds the minimal power of the wind turbine The load is switched off by priorities until the maximum power of the wind turbine is more than the demand

6.2 Autonomous Systems with a Fuel Engine Having a Rating Similar to that of Wind Turbine

These systems are designed to offer a constant supply of energy, independent of the wind speed Such systems during operation may encounter three different situations

- The demand is less than the power available from wind turbine and all the demand power is supplied by the wind turbine

- The demanded power is more than the power available from wind turbine and the parallel operation of wind turbine and the fuel engine takes place

- No wind power is available and all the power is supplied by a fuel engine

The frequency control is again a major problem and the alternative techniques are

- By means of controlling the field current of synchronous generator.

- By controlling the rotor slip power of the induction generator.

- By using dump loads.

- Mechanically varying the RPM of rotor to keep the frequency constant

- By using controllable speed variator which gives constant RPM on the output shaft

6.3 AC Systems with Fuel Component of much Higher Rating than that of the Wind Turbine

These systems are not autonomous systems but supplement the diesel grid which is comparable with a strong utility grid The demanded power is always greater than the power supplied by the wind turbine so there is no need for an extra load to control the power balance The frequency in all cases is controlled by the diesel's governor In nearly all known systems the wind turbine drives an asynchronous generator

6.4 Storage Systems

There are a number of small DC systems up to 5 kW combined with an inverter to get AC output These systems are composed of the following major sub-elements

- a wind turbine with a DC generator or an AC generator (permanent magnet synchronous) with a rectifier

- a storage battery

- a voltage source inverter

Small capacity battery storage systems are usually used to supply DC loads and inverters are not used

7.0 Mechanical Output Wind Machines

The mechanical output wind machines are mostly used for pumping water. Direct shaft power has also been tried for other applications like grinding or heat generation. While heat generation has not been found to be a very cost effective way, the use of windmills for grinding grains which has been one of the applications of traditional windmills has declined now A brief description of these types are made under section 4.1.

7.1 Windpump Technology

At present nearly all mechanical output windmills are used for pumping water and the system is known as a windpump The most widely used windmills are those that have horizontal axis rotors with multiple blades The rotary motion of the rotor shaft is converted to either vertical reciprocating motion by various mechanisms or vertical rotary motion using gears. The simplest technique is the slider crank mechanism with or without speed reduction (by gears) Some machines also use bevel gears The vertically reciprocating pump rod is connected to a reciprocating pump which demands high initial torque whereas the vertically rotating pump rod is connected to either a centrifugal pump or a rotary vane pump The rotary movement of a horizontal axis rotor shaft can be easily transformed into reciprocating movement by means of crank-connecting rod Due to the high initial torque demanded by a reciprocating pump the windmill rotor is designed with multiple blades which operate at low tip speed ratio The starting behavior of a windpump is such that it requires a gust of wind about 1.5 times the design wind speed The major sub-systems of a wind pump are

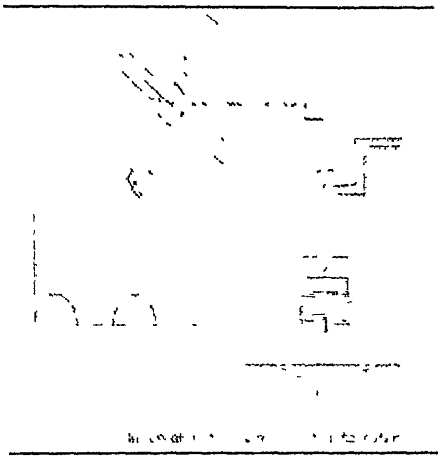

Figure 16 Working of a Windpump

Rotor The rotor of a windmill consists of few *blades* (4-24) mounted on one or two *rings* (depending upon dia) and *spokes* which is in turn bolted to the rotor

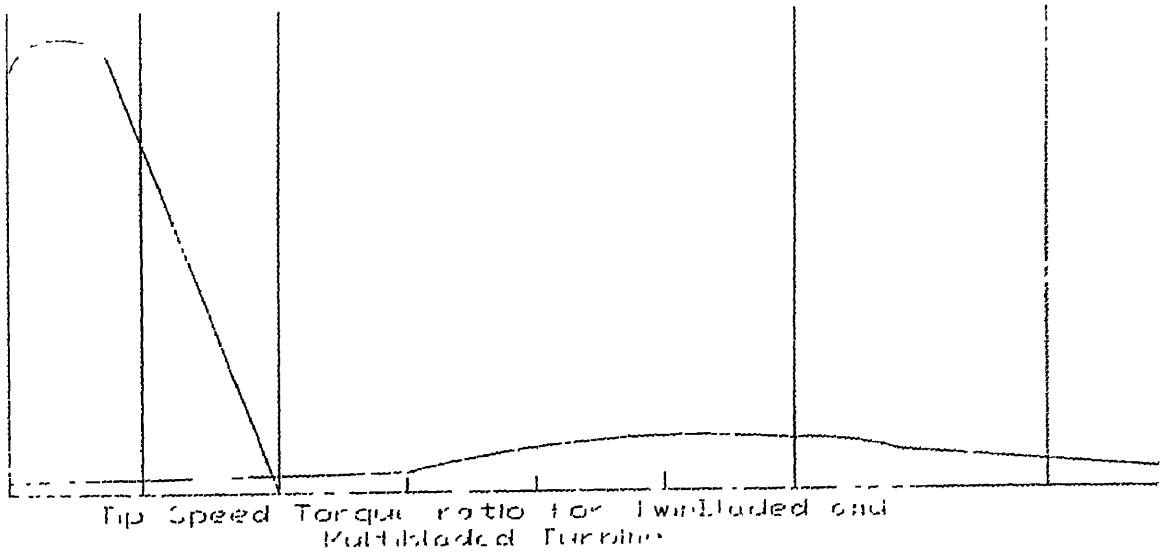

Figure 17 Speed Torque Ratio

hub. The blades are made of either aluminum, M.S sheets, G I sheets or FRP and are fixed aerodynamically to the rotor The rings, spokes and *blade supports* are fabricated of steel angle irons or flats The rotor, however, can also be of other types like vertical axis savonius, with sail cloth blades etc..

Head Structure The head structure of a wind mill is a steel structure usually fabricated of angle irons/pipes or is casted in a foundry The rotor, tail wing and the power transmission components are mounted on the head structure.

Turn table The turn table made of steel is fixed to the tower and the windmill head structure is mounted on it The turn table transmits the load of the rotor, head structure, tail wing etc to the tower and at the same time enables the head structure to rotate about the tower axis.

Tower Tower is made of M S angles and flats or G I. pipes and is usually made in two-three sections It holds the head mechanism at a height that varies from 6 m to 15 m The head mechanism in turn holds the rotor, tail and other components Towers are usually three legged or four legged lattice structures

Pump The most widely used windpumps operate a single acting reciprocating pump The reciprocating piston pump basically consists of a cylinder made of brass/bronze with or without cast-iron covering, a piston and two non-return valves The output from the pump is in sinusoidal pulses and sometimes air chambers are utilized to smoothen the flow and to reduce shock forces. The upper valve is mainly situated in the piston, the lower valve is called the foot valve The operation is as follows The upper valve closes with the upward movement of the piston while the foot valve opens so that the water above piston is lifted while below it suction takes place The pump discharge, therefore, is pulsating sinusoidal Sometimes double acting pumps are used with pistons moving in opposite directions, thus delivering water during the gaps in the flow of a single acting pump

Control and Safety Mechanism Wind mills are designed/fabricated to operate with in a particular range of wind speeds The control mechanism operates within this range wherein it controls the rotor speed and the safety mechanism operates after the operating range wherein it stops the operation of the system Autofurling, side vane & ratchet mechanism and brake drums etc are examples of control and safety mechanisms

7.2 Developments & Status

Wind pumps first arrived in the country in the 1950's About a 100 Australian wind pumps were imported, aimed provide drinking water After the set back during the industrial revolution, wind energy received a major thrust in the early 70's following the oil crisis. Multidirectional CEZARI was developed in 1975, bi-directional ANILA I in 1978, the NAL-MP series was developed in early 1980. IERT, Alahabad with technical backup from the Tool Foundation, The Netherlands, fabricated the Apoly 12 PU 500 windpump based on a dutch design This project was aimed at harnessing wind power for irrigational applications

Absence of a national programme was felt by this time to take this technology all over the country. Thus in the beginning of 1980, MNES started nation wide Demonstrational Programme The 12 PU 500 wind pump was selected for this programme mainly due to its low cost, promising tech

However, the field performance of the system was not satisfactory as expected due to reasons - both technical as well as implementing strategy wise Currently the MNES has shifted to geared type deepwell wind pumping systems This change was brought due the poor performance of 12 PU 500 in the field even after several design modifications and varying implementing strategies Other possible reasons are water table going deeper and deeper, the deepwell technology being proven in the foreign countries The deferent types of wind pumps installed in the country is listed in table 9 and the state wise installations of geared type wind pumps is as shown in table 10

Table 9: Different types of wind pumps in India.

Make	**Rotor dia. ([illegible])**	**No. of blades**	**Tower height ([illegible])**	**Pump type**	**Ave. rate of discharge (lit/hr)**
12 PU 500	5 0	12	7	Reciprocating	18,000
WF 305 G	3 05	18	10	Reciprocating	2,000
WF 250 G	2 5	12	10	Reciprocating	1,500
Green Rev DWP 150	3.0	18	10-15	Reciprocating	2,350
DW 300 G	3 0	12	9	Reciprocating	1,500
Samira	7 5	3	6	Centrifugal	18,500
Blue Tail	5 0	24	10	Reciprocating	*
Strucon	5 0	24	10	Reciprocating	*
GM-2	3 0	18	10	Reciprocating	*

* Exact values not available

Table 10: State wise installation of Geared Type Wind Pumps

Sl No	States	Installed as on 31.3.92	Installed as on 31.12.92	Under installation
1	Andhra Pradesh	10	10	-
2	Gujarat	-	10	30
3	Karnataka	4	20	-
4	Kerala	10	15	5
5	Madhya Pradesh	3	10	10
6	Maharashtra	19	23	7
7	Rajasthan	16	19	1
8	Tamil Nadu	50	60	-
9	Uttar Pradesh	-	5	15
	Total	112	172	68

Source Annual report 1992-93 MNES